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Invited Paper

Low-coherence interference microscopy at high numerical apertures

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ABSTRACT

A white-light Linnik interference microscope using high numerical aperture optics has been constructed. The system uses a tungsten halogen source and Köhler illumination with separate control over field and aperture stops, so that experiments can be conducted with a range of different operating conditions. Infinity tube length objectives are used in the two arms. Images are recorded with a CCD camera. Different algorithms have been investigated for extraction of information from the image data. These are based on phase stepping, which is achieved based on the principle of the geometric phase, using a polarizing beam splitter, a quarter wave plate and a rotating polarizer. Image information extracted from the visibility of the fringes and also from the phase of the interference fringes has been investigated.

Keywords: Low-coherence interferometry, optical coherence tomography, coherence-probe microscope, white-light interferometry, phase-shifting, geometric phase, surface profiling.

1 INTRODUCTION

Recently white-light interferometry (WLI) has grown in importance in a variety of applications documented by various authors. These iclude 3–D imaging for medical diagnostics using optical coherence tomography (OCT),[1,2] in optical fibre sensors[3-5] and in a surface profiling techniques using coherence probe microscopy (CPM).[6-11] It has many advantages over the conventional (monochromatic) interferometric techniques. The most promising property of WLI is that it can overcome the ambiguity problems, inherent to monochromatic interferometric systems. WLI systems have a virtually unlimited unambiguous range, so that surfaces can be measured without using phase unwrapping techniques. Another important characteristic of WLI is its optical sectioning property. This is due to the short coherence length of the source, so that the interference term is appreciable only for a short range of depths, and hence an optical section is extracted which allows three-dimensional images to be formed.

In this technique the images are produced by scanning the object in depth and calculating the degree of coherence (visibility peak) between corresponding pixels in the object and reference image planes. In OCT this is done using heterodyning techniques. A single point is observed and an image built up by scanning. In our work, as in CPM, a complete two-dimensional image is observed using a CCD detector. While various digital filtering techniques have been used to recover the fringe visibility curve, they tend to be numerically intensive. The use of conventional phase-shifting technique to simplify the processing is complicated by the fact that the phase shift introduced by changing the optical path is wavelength dependent, leading to systemic errors in the fringe visibility. An alternative way to achieve phase shifting is by means of the geometric phase (Pancharatnam phase).[12,13] This is the phase shift experienced by a light beam as a result of a cyclic change in its state of polarization. Because the geometric phase is a topological phenomenon, it is, in principle, independent of the wavelength.

2 EXPERIMENTAL SET-UP

A schematic diagram of the white-light interference microscope is depicted in Fig. 1. A tungsten halogen lamp (12V, 100W) is used as a source. The linearly polarized beam transmitted by the polariser is divided at the polarising beam splitter into two orthogonally polarised beams which are focused on to a reference mirror and a specimen by two identical infinity tube-length 40X microscope objectives with numerical aperture 0.75. After reflection at the reference mirror and object these beams return along their original paths to a second beam-splitter which sends them through a second polarizer to the CCD camera.

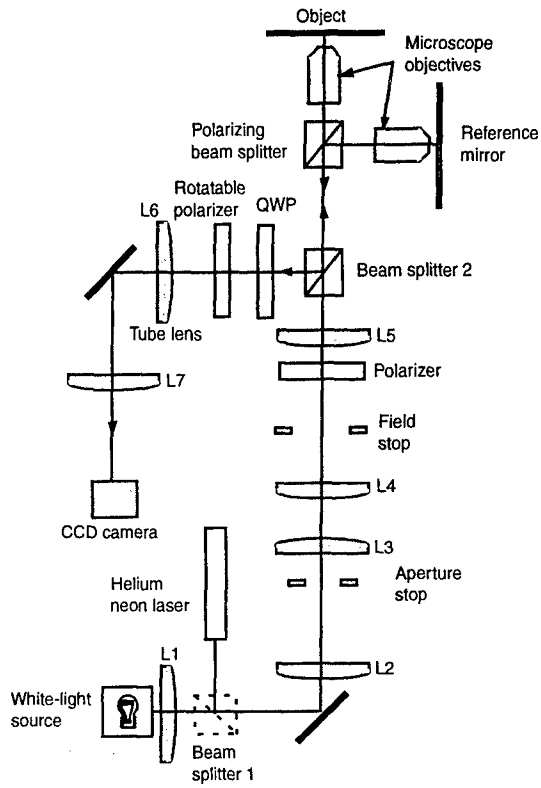

Fig.1. The white-light interferometric microscope

The phase difference between the beams was varied by a Geometric Phase-Shifter (GPS) consisting of a quarter-wave plate (QWP) with its axis fixed at an azimuth of 45°, and a polarizer which can be rotated by known amounts. In this case, if the polarizer is set with its axis at an angle θ to the axis of the QWP, the linearly polarized beam reflected from the reference mirror acquires a geometric phase shift equal to 2θ. The orthogonally polarized beam from the specimen acquires a geometric phase shift equal to -2θ, so that the additional phase difference introduced between the two beams is 4θ. This additional phase difference is very nearly independent of the wavelength.

A 3mW He-Ne laser is also provided. Since the coherence legth of the laser is much longer than that of the white-light source, the laser is used for finding the interference fringes.

The operation of the achromatic phase shifter was verified by observation of the fringe system obtained by tilting the reference mirror slightly and by using a mirror as a test surface. With monochromatic illumination, rotation of the polarizer resulted in a continuous movement of the interference fringes across the field of view. When the direction of rotation of the polarizer was reversed, the fringes moved continuously in the opposite direction.

To illuminate the object uniformly, a Koehler illumination system is used, consisting of lenses L1-L4 together with a microscope objective. This system allows separate control of both the illumination aperture stop and the field stop. Stopping down the illumination aperture allows the system to be operated as a conventional interference microscope.

Reducing the field of view keeps the scattered light collected by the detector to a minimum and keeps specimen heating to a minimum. Field of view of the system is 25μm X 43μm.

The object is scanned along the z axis by means of a piezoelectric transducer (PZT) over a range of 5μm centred approximately on the zero-order white light fringe. At each step, three, four or five measurements were made of the intensity, depending on which phase-shifting algorithm was used. We obtained best results with the five-step algorithm. Since the additional phase differences introduced by the GPS are the same for all wavelengths, the visibility of the interference fringes at any given point in the field can be extracted. The visibility falls off as a result of both the coherence length of the source and the correlation effect,[8] which give similar sectioning to that in confocal microscopy.

When observing a surface structure, for example an integrated circuit, as specimen, the surface height can be extracted by finding for each pixel the peak of the visibility variation. This can be done by various algorithms. We found a good algorithm was to fit a parabola through three points. Surface height can also be determined from observation of the phase of the interference fringes.

3. DISCUSSION

We have shown the successful use of GPS for white-light interferometric surface profiling on a microscopic scale. The range of surface height that can be profiled with this technique is limited only by the characteristics of the PZT used to translate the specimen along the z axis and the available computer memory. However, since the steps between height settings at which data have to be taken can correspond to changes in the optical path difference of the order of a wavelength or more, a much smaller number of steps are required to cover a large range of depths than for conventional WLISP.

Phase shifting at each step can be carried out rapidly in an actual contouring system, by replacing the rotating HWP plate in the phase shifter with a pair of Ferro-electric Liquid Crystal (FLC) devices. With these devices, it is possible to implement the phase shift at each step within a few milliseconds making this only a small time penalty compared to the 40ms video frame period. Eventually, this will allow acquisition of the intensity data much more rapidly than any scheme using PZT phase stepping alone.

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REFERENCES

1. D. Huang, E. A. Swanson, C. P. Lin, J. S. Schuman, W. G. Stinson, W. Chang, M. R. Lee, T. Flotte, K. Gregory, C. A. Puliafito and J.G. Fujimoto, Optical Coherence Tomography, *Science*, **254**, pp.1178-1181, 1991.
2. J. M. Schmitt, A. Knüttel and R. F. Bonner, Measurement of optical properties of biological tissue by low coherence reflectometry, *Appl. Opt.*, **32**, pp. 6032-6042, 1993.
3. S. Chen, A. W. Palmer, K. T. V. Grattan and B. T. Meggitt, Digital signal-processing techniques for electronically scanned optical-fiber white-light interferometry, *Appl. Opt.*, **31**, pp. 6003-6010, 1992.
4. Y. J. Rao, Y. N. Ning and D. A. Jackson, Synthesized source for white-light sensing systems, *Opt. Lett.*, **18**, pp. 462-464, 1993.
5. M. V. Plissi, A. L. Rogers, D. J. Brassington and M. G. F. Wilson, Low-coherence interferometric system utilizing an integrated optical configuration, *Appl. Opt.*, **34**, pp. 4735- 4739, 1995.
6. M. Davidson, K. Kaufman, I. Mazor and F. Cohen, An application of interference microscopy to integrated circuit inspection and metrology, *Proc. SPIE*, **775**, pp.233-247, 1987.
7. B. L. Danielson and C. Y. Boisrobert, Absolute optical ranging using low coherence interferometry, *Appl. Opt.*, **30**, pp. 2975-2979, 1991.
8. S. S. C. Chim and G. S. Kino, Correlation microscope, *Opt. Lett.*, **15**, pp. 579-581, 1990.
9. T. Dresel, G. Häusler and H. Venzke, Three dimensional sensing of rough surfaces by coherence radar, *Appl. Opt.*, **31**, pp. 919-925,1992.
10. L. Deck and P. d. Groot, High-speed noncontact profiler based on scanning white-light interferometry, *Appl. Opt.*, **33**, pp. 7334-7338,1994.
11. P. Sandoz, An algorithm for profilometry by white-light phase-shifting interferometry, *J. Mod. Opt.*, **43**, pp.

1545-1554, 1996.
12. M.V. Berry, The adiabatic phase and Pancharatnam's phase for polarized light, *J. Mod. Opt.*, **34** , pp. 1401-1407, 1987.
13. P. Hariharan and M. Roy, A geometric-phase interferometer, *J. Mod. Opt.*, **39**, pp. 1811-1815, 1992.